National Aeronautics and Space Administration

George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

June 8, 2015

Reply to Attn of: EV44 (15-004)

TO: KSC/SIB20/Lisa Huddleston

FROM: EV44/Ryan K. Decker

SUBJECT: KSC 50-MHz Doppler Radar Wind Profiler (DRWP) Operational Acceptance Test (OAT) Report

This memorandum and the attachment contain details of the analyses conducted by the MSFC Natural Environments Branch/EV44 as part of the OAT for the KSC 50-MHz DRWP replacement project. The purpose of the OAT was to evaluate the functional performance of the new DRWP so end users can use the data for situational awareness during mission operations on the Eastern Range (ER) prior to full system certification. This was accomplished through analyses to verify the quality and accuracy of the meteorological data output from the new DRWP system in comparison to the performance of the previous DRWP. The analysis results showed the new system performs as well as the previous system and EV44 recommends acceptance of the new DRWP for use in support of launch operations as a situational awareness tool.

For additional information please contact the undersigned at (256) 544-3068.

Ryan K. Decker

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Natural Environments Branch

Concurrence:

B. Glenn Overbey
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6/8/15
Date

Attachment:
Jacobs Tech Report – ESSSA-FY15-1287

cc:
MSFC/EV40/D. Krupp
KSC/SIB20/L. Maier

Results of the Updated Kennedy Space Center 50-MHz Doppler Radar Wind Profiler Operational Acceptance Test

BJ Barbré / Jacobs ESSSA Group / MSFC Natural Environments Branch

Executive Summary

This report documents analysis results of the Kennedy Space Center (KSC) updated 50-MHz Doppler Radar Wind Profiler (DRWP)'s Operational Acceptance Test (OAT). This test was designed to demonstrate that the new DRWP operates in a similar manner to the previous DRWP for use as a situational awareness asset for mission operations at the Eastern Range (ER) to identify rapid changes in the wind environment that weather balloons cannot depict. Data examination and two analyses showed that the updated DRWP meets the specifications in the OAT Test Plan and performs at least as well as the previous DRWP. Data examination verified that the DRWP provides complete profiles every five minutes from 1.8-19.5 km in vertical increments of 150 m. Analysis of 5,426 wind component reports from 49 concurrent DRWP and balloon profiles presented root mean square (RMS) wind component differences around 2.0 m/s. The DRWP's effective vertical resolution (EVR) was found to be 300 m for both the westerly (U) and southerly (V) wind component, which is the best EVR possible given the DRWP's vertical sampling interval. A third analysis quantified the sensitivity to rejecting data that do not have adequate signal by assessing the number of first-guess propagations at each altitude. This report documents the data, quality control procedures, methodology, and results of each analysis. It also shows that analysis of the updated DRWP produced results that were at least as good as the previous DRWP with proper rationale. The report recommends acceptance of the updated DRWP for situational awareness usage as per the OAT's intent.

1. Introduction

This report documents the methodology and results of the new KSC 50-MHz DRWP's OAT. On day-of-launch (DOL), space launch vehicle operators have used data from the DRWP to invalidate winds in prelaunch loads and trajectory assessments due to the DRWP's capability to quickly identify changes in the wind profile within a rapidly-changing wind environment. The previous DRWP has been replaced with a completely new system, which needs to undergo certification testing before being accepted for use in range operations. The new DRWP replaces the previous three-beam system made of coaxial cables and a copper wire ground plane with a four-beam system that uses Yagi antennae with enhanced beam steering capability. In addition, the new system contains updated user interface software while maintaining the same general capability as the previous system. The new DRWP continues to use the Median Filter First Guess (MFFG) algorithm to generate a wind profile from Doppler spectra at each range gate. Reference [1] contains further details on the upgrade. The OAT is a short-term test, approved by the DRWP Certification team, designed so that end users can utilize the new DRWP in a similar manner to the previous DRWP during mission operations at the ER in the midst of a long-term certification process. This report describes the Marshall Space Flight Center Natural Environments Branch's (MSFC NE's) analyses to verify the quality and accuracy of the DRWP's meteorological data output as compared to the previous DRWP. Ultimately, each launch vehicle program has the responsibility to certify the system for their use.

Table 1: List of acronyms.

AMPS	Automated Meteorological Profiling System
CCWS	Cape Canaveral Weather Station
CSD	cross spectral density
DOL	day-of-launch
DRWP	Doppler Radar Wind Profiler
ER	Eastern Range
EVR	effective vertical resolution
FFT	Fast-Fourier Transform
FGP	first-guess propagation
HRFE	High Resolution Flight Element
KSC	Kennedy Space Center
LRFE	Low Resolution Flight Element
MFFG	Median Filter First Guess
MIDDS	Meteorological Interactive Data Display System
MSFC NE	Marshall Space Flight Center Natural Environments Branch
PSD	power spectral density
QC	quality control
RMS	root-mean-square

2. DRWP Validation Specifications

The OAT Test Plan [2] outlines the OAT's intentions and validation criteria, which are presented in Table 2. The variables of interest consist of obtaining required data and validating the specified time interval, vertical data interval, altitude, wind accuracy, and EVR. Criteria for the first three variables parallel the data reporting characteristics of the previous DRWP, and MSFC NE confirmed that all of these variables passed their respective criterion during data processing. MSFC NE performed analyses of the DRWP itself

to assess the EVR criteria. To address wind accuracy, MSFC NE compared concurrent DRWP and Automated Meteorological Profiling System (AMPS, [3]) balloon profiles. From [2], at least 30 concurrent profiles in conditions where the balloon would not drift far downrange were desirable. AMPS Low-Resolution Flight Element (LRFE) and High-Resolution Flight Element (HRFE) profiles were released during operations at the Cape Canaveral Weather Station (CCWS) during normal synoptic or mission support. Lastly, MSFC NE used techniques to temporally and vertically match the DRWP and AMPS data.

Table 2: NASA 50-MHz DRWP OAT criteria.

Required Data	Wind Speed and Direction, Altitude, Shear, Radial Velocities, Signal Power, Noise Power, Spectral Width
Time Interval	5 min
Vertical Data Interval	150 m
Altitude	2.0-18.6 km
Wind Accuracy	1.5 m/s RMS component difference
Effective Vertical Resolution	500 m

The OAT used previous test results to assess the DRWP's wind accuracy and EVR criteria shown in Table 2. A similar comparison of DRWP and AMPS data after an upgrade to the previous DRWP [4] provided the basis for the OAT's 1.5 m/s root-mean-square (RMS) wind component difference criteria. This study generated RMS U- and V-component differences of 1.57 m/s and 1.56 m/s, respectively, given that the balloon was less than 50 km downrange or not within a large horizontal wind gradient. However, using all balloons produced RMS U- and V-component differences of 1.70 and 1.65 m/s, respectively. This characteristic highlighted the influence of the balloon drifting with the wind, and MSFC NE addressed this criterion with the understanding that the OAT's results could be easily higher than 1.50 m/s yet still be acceptable. Similarly, the OAT used the results from a spectral analysis performed on the previous DRWP [5] as a basis for the 500-m wind component EVR, with the understanding that valid characteristics in the data could produce an EVR greater than 500 m. Thus, MSFC NE's intention consisted of assessing results of the new DRWP data against the criteria in Table 2, documenting possible reasons for any discrepancy, and determining if these reasons are valid. The report herein describes in detail the OAT's data, analyses, results, and recommendation.

3. Data Obtained for Analysis

MSFC NE utilized DRWP data that came through the Meteorological Interactive Data Display System (MIDDS) for the OAT, of which the data collection period existed from 6 January 2015 through 19 February 2015. DRWP MIDDS output contains altitude, wind speed, wind direction, radial shear, vertical velocity, signal power, noise level, number of first-guess propagations (FGPs), and quality control flags for each profile. The new DRWP is a four-beam system and the MIDDS file format could not be changed from the previous three-beam system. Therefore, the oblique beam signal, noise, and spectral width fields represent opposing-beam averages and the vertical beam field represents averages over all beams. In addition, the FGP field represents the opposing-beam maximum. Approximately five minutes exist between temporally adjacent profiles, and altitude coverage ranges from 1,798-19,645 m, at 150 m intervals.

MSFC NE collected AMPS balloon data through MIDDS as well for the DRWP and AMPS balloon comparison. The CCWS released all balloons under normal synoptic and mission support operations. All

LRFE and HRFE profiles transmitted through MIDDS were examined for wind profiles reporting winds at 30.48 m altitude intervals. Interpolation from one-second measurements produced the wind components at these altitudes. LRFEs typically reach roughly 30 km and consist of wind speed, wind direction, and thermodynamic data. The HRFEs typically reach 16-17 km. HRFE MIDDS output does not contain thermodynamic data, but does contain rise rate. Thus, the OAT used the rise rate directly from the HRFE profiles and assumes a constant rise rate of 5.1816 m/s, or 17.0 ft/s to assess LRFE profiles. The CCWS also provided MSFC NE with weather observer logs for each balloon release.

MSFC NE implemented specific quality control (QC) procedures for each analysis, with the general philosophy that the OAT should evaluate the functionality of the DRWP system as the system was designed. Therefore, an extensive QC effort (e.g., [6, 7, and 8]) was not applied to the OAT DRWP database before analysis. Sections describing individual analyses provide the respective QC procedures used.

4. Supporting Analyses

a. Comparison of Concurrent Balloon and DRWP Wind Components

The balloon / DRWP comparison utilized concurrent winds from balloon and DRWP data that met specified criteria. First, the analysis extracted candidate AMPS LRFE and HRFE profiles. These profiles contained wind reports at 30.48 m intervals to at least 15.24 km and at least five minutes existed between temporally adjacent releases. From these profiles, a shear quality control (QC) check removed 0.2% of individual balloon winds that failed a vector wind shear check of 0.15 s^{-1} over 30.48 m. Balloon data preprocessing derived wind components, as well as two displacement variables, which the DRWP comparison used:

- The timestamp at each altitude, which utilized the balloon's release time, rise rate, and altitude.
- Horizontal distance from the DRWP's vertical plane at each altitude.

Next, the balloon / DRWP comparison extracted DRWP profiles during days that contained balloon data. For initial analysis, the comparison implemented vector shear and convection checks on all DRWP data on days where candidate balloon profiles existed. The analysis implemented these checks to parallel the QC performed on the balloons and to remove cases where the environment was known to contaminate output from both DRWP and balloon systems. All DRWP measurements on these days contained vector shear at or below 0.15 s^{-1} over 150 m. The analysis addressed convection through examining the CCWS weather log and time-height sections of output from the algorithm used to determine convection for MSFC NE's 50-MHz DRWP archive [8]. One discerned convection if the log contained a report that could indicate convection in the area (e.g., overcast skies, rain, or high surface winds) and the algorithm from [8] indicated that convection could have occurred. Table 3 shows the days and time periods at which all DRWP profiles were removed due to convection.

Table 3: Days and timestamps at which DRWP profiles were removed due to convection.

Day	Time Period Containing Convection
1/12/2015	2000-2359
1/13/2015	0000-0400
1/15/2015	1900-2359
1/16/2015	0000-2359
2/2/2015	1300-1500
2/5/2015	0700-1800
2/13/2015	1800-2000
2/16/2015	1900-2200
2/18/2015	0000-0800

The algorithm then matched candidate balloon and DRWP profiles in the vertical domain to mitigate the discrepancies inherited from each source sampling at different altitude intervals. To vertically match data from the two systems, the algorithm extracted balloon data at each DRWP altitude. First, the candidate balloon profile's wind components, timestamps, and horizontal displacement were interpolated at 0.3048 m, or 1.0 ft intervals. Next, the process averaged each quantity existing within 75.0 m of each DRWP altitude. Figure 1 illustrates this concept for the U wind component. All 0.3048 m values of U within 75.0 m of the DRWP's altitude of 3,898 m were averaged to obtain U representing the balloon's output at this DRWP altitude. Last, the analysis repeated this process for all candidate balloon profiles and DRWP altitudes.

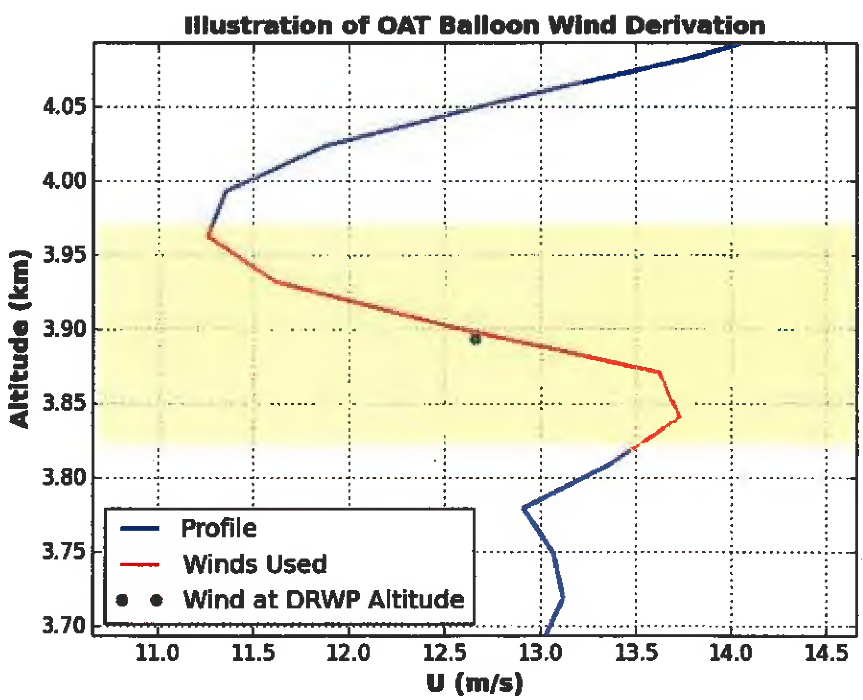

Figure 1: Example of balloon U derived at an individual DRWP altitude.

In addition, the algorithm matched concurrent data temporally to address each source's temporal sampling characteristics. The balloon takes roughly 60 minutes to reach the maximum DRWP altitude.

Thus, the DRWP generates multiple profiles during the balloon's ascent, with higher portions of the DRWP profile representing the altitude regime later in the balloon's flight. Figure 2 illustrates how concurrent DRWP profiles were generated for the OAT. First, the algorithm subtracted 7.5 minutes from the DRWP's timestamp to account for the DRWP profile essentially representing an average wind profile over the previous 15-minutes [9]. Next, the algorithm found DRWP winds that existed within 10 minutes of the balloon's timestamp at the DRWP's altitude. The latter check was performed to avoid the closest DRWP timestamp being too far removed from the balloon's timestamp at a given altitude. In Figure 2, the DRWP profile used for comparison consists of ~2.0-km segments from 12 individual DRWP profiles. Last, the process accepted the concurrent DRWP and balloon profile if at least 75% of concurrent data existed below 15.24 km.

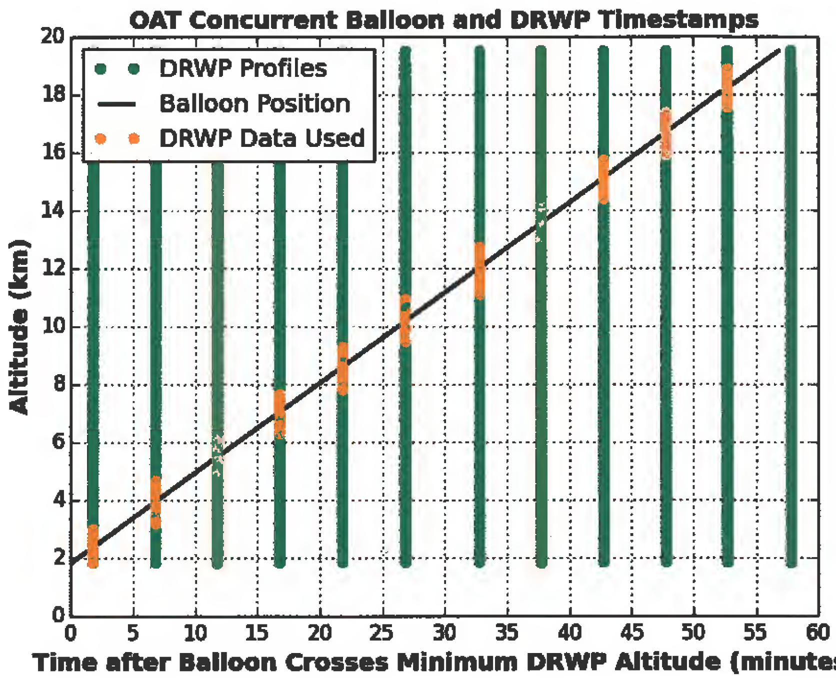

Figure 2: Illustration of temporally matching balloon and DRWP profiles. Orange segments of each DRWP profile indicate the portion of the DRWP profile that exists closest to the balloon wind at the DRWP's altitude.

The process then implemented a manual QC check on each set of concurrent profiles to ensure that one or both systems do not contain artificial, non-meteorological reports that could contaminate the wind component comparison. This process first examined each set of concurrent profiles and DRWP time-height sections during the same day. Figure 3 highlights such a comparison. Profiles containing vector differences greater than 15 m/s were more closely scrutinized. Concurrent data, where one or both systems seemed to report suspect data that does not correspond to a meteorological feature, were removed. Large differences produced by different meteorological conditions were retained. Figure 3 shows an example of the latter near 12-13 km. During this time period large gradients in V existed and the balloon and DRWP sampled different wind environments at the same altitude. Specifically, one could discern that the balloon sampled the wind regime that existed over the DRWP just before 1000 UTC – and that this regime had migrated downrange (via U ~65 m/s) into the balloon's ascent path by the time the balloon reached 12 km at approximately 1145 UTC. The manual process removed four individual reports from all concurrent balloon and DRWP profiles.

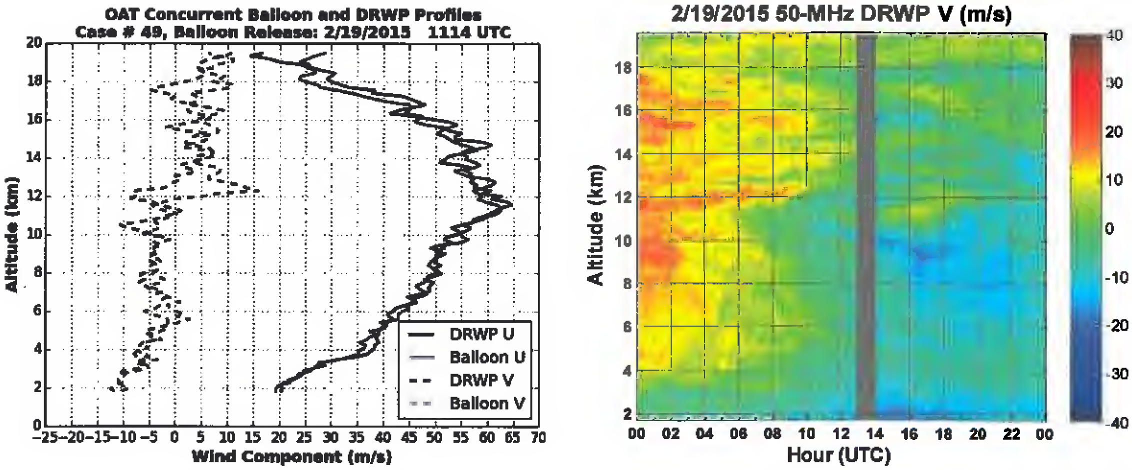

Figure 3: Example of concurrent DRWP and balloon profiles (left) and the corresponding time-height section of DRWP V (right).

The resulting dataset consisted of 5,426 reports from 49 concurrent DRWP and balloon profiles. Table 4 lists the date and timestamp of each balloon used during the OAT, as well as a general description of the sky cover and wind environment during each release. Multiple profiles existed on 6 January, 10 January, 20 January, 21 January, 8 February, and 11 February. The resulting balloon dataset consisted of one HRFE profile and 48 LRFE profiles. The reason for so few HRFEs is that they either did not reach 15.24 km and/or were released on days where DRWP data were not available. Because data were collected during winter, many of the balloon profiles were released in strong and / or dynamic wind environments. Figure 4 shows all of the balloon U and V profiles used for the OAT. Median U reached 35-40 m/s, and maximum U approached 70 m/s. Envelopes of V ranged from -15 to +15 m/s, varying slightly with altitude. Examining these plots revealed that balloons likely drifted significantly down range (to the east) into different wind regimes, which could influence statistical results.

Table 4: Balloon profiles used during the OAT with corresponding sky cover and wind environment descriptions.

Case #	Balloon	Date	Time (UTC)	Sky Conditions and General Wind Environment
1	LRFE	1/6/2015	0625	Mostly cloudy. WSW flow with peak winds near 40 m/s. Enhanced WNW feature around 14 km.
2	LRFE	1/6/2015	0649	Mostly cloudy. WSW flow with peak winds near 40 m/s. Enhanced WNW feature around 14 km.
3	LRFE	1/6/2015	0819	Mostly cloudy. WSW flow with peak winds near 40 m/s. Enhanced WNW feature around 14 km.
4	LRFE	1/6/2015	0934	Mostly cloudy. WSW flow with peak winds near 40 m/s. Enhanced WNW feature around 14 km.
5	LRFE	1/7/2015	1114	Clear. W flow with peak winds near 50 m/s. Enhanced WNW feature around 16 km.
6	LRFE	1/8/2015	1114	Partly Cloudy. WSW flow from 8-16 km with peak winds near 50 m/s. WNW flow with peak winds near 30 m/s from 2-8 km.
7	LRFE	1/9/2015	1114	Mostly cloudy. WSW flow with peak winds near 40 m/s.
8	LRFE	1/10/2015	0346	Sky cover N/A. WSW flow with peak winds near 40 m/s.
9	LRFE	1/10/2015	0516	Sky cover N/A. WSW flow with peak winds near 40 m/s.
10	LRFE	1/10/2015	0646	Sky cover N/A. WSW flow with peak winds near 40 m/s.
11	LRFE	1/10/2015	0801	Sky cover N/A. WSW flow with peak winds near 40 m/s.
12	LRFE	1/10/2015	1114	Mostly cloudy. WSW flow with peak winds near 40 m/s.
13	LRFE	1/11/2015	1114	Mostly cloudy. WSW flow with peak winds near 40 m/s. Enhanced W flow from 8-16 km.
14	LRFE	1/12/2015	1114	Mostly cloudy. WSW flow with peak winds near 40 m/s. Enhanced W flow from 8-16 km.
15	LRFE	1/13/2015	1114	Mostly cloudy. Dynamic wind regime. WSW flow with peak winds near 40 m/s.
16	LRFE	1/14/2015	1114	Overcast. SW flow with peak winds near 50 m/s, enhanced from 8-15 km.
17	LRFE	1/17/2015	1114	Partly cloudy. WNW flow with peak winds near 60 m/s.
18	LRFE	1/18/2015	1114	Mostly cloudy. WSW flow with peak winds near 50 m/s.
19	LRFE	1/19/2015	1114	Clear. NW flow below 10 km, WSW flow above 10 km. Peak winds near 50 m/s.
20	LRFE	1/20/2015	1114	Overcast. W flow above 4 km. Peak winds near 50 m/s. Enhanced SW flow near 11 km.
21	LRFE	1/20/2015	1712	Sky cover N/A. W flow above 4 km. Peak winds near 50 m/s. Enhanced SW flow from 8-10 km.
22	LRFE	1/20/2015	1957	Sky cover N/A. S flow below 4 km, W flow above 4 km. Peak winds near 60 m/s.
23	LRFE	1/20/2015	2127	Sky cover N/A. SW flow below 4 km, WNW flow from 5-16 km. Peak winds near 70 m/s.
24	HRFE	1/20/2015	2253	Sky cover N/A. SW flow below 4 km, WNW flow from 4-16 km. Peak winds near 70 m/s.
25	LRFE	1/20/2015	2317	Sky cover N/A. SW flow below 4 km, WNW flow from 4-16 km. Peak winds near 70 m/s.
26	LRFE	1/20/2015	2337	Sky cover N/A. SW flow below 4 km, WNW flow from 4-16 km. Peak winds near 70 m/s.
27	LRFE	1/21/2015	0017	Sky cover N/A. SW flow below 4 km, WNW flow from 4-16 km. Peak winds near 70 m/s.
28	LRFE	1/21/2015	0037	Sky cover N/A. SW flow below 4 km, WNW flow from 4-16 km. Peak winds near 70 m/s.
29	LRFE	1/21/2015	1114	Clear. NW flow below 14 km. W flow above 14 km. Peak winds near 70 m/s.
30	LRFE	1/22/2015	1114	Partly cloudy. W flow with peak winds near 60 m/s.
31	LRFE	1/23/2015	1114	Mostly cloudy. W flow with peak winds near 50 m/s. Enhanced SW flow near 13 km.
32	LRFE	2/3/2015	1114	Partly cloudy. W flow with peak winds near 50 m/s.
33	LRFE	2/6/2015	1114	Partly cloudy. Dynamic wind regime. NW flow with peak winds near 50 m/s.
34	LRFE	2/7/2015	1114	Clear. NW flow with peak winds near 40 m/s.
35	LRFE	2/8/2015	1114	Mostly cloudy. SW flow below 10 km. NW flow from 11-16 km. N flow above 16 km. Peak winds near 30 m/s.
36	LRFE	2/8/2015	1709	Sky cover N/A. SW flow below 10 km. NW flow from 11-16 km. N flow above 16 km. Peak winds near 30 m/s.
37	LRFE	2/8/2015	1839	Sky cover N/A. SW flow below 6 km. W flow from 6-14 km. NNW flow above 14 km. Peak winds near 30 m/s.
38	LRFE	2/8/2015	2009	Sky cover N/A. WSW flow below 10 km. NNW flow above 10 km. Peak winds near 30 m/s.
39	LRFE	2/8/2015	2124	Sky cover N/A. WSW flow below 10 km. NNW flow above 10 km. Peak winds near 30 m/s.
40	LRFE	2/9/2015	1114	Mostly cloudy. Dynamic wind regime. W flow with peak winds near 30 m/s. Enhanced NW flow near 11 km.
41	LRFE	2/11/2015	1702	Sky cover N/A. WNW flow below 10 km. WSW flow above 10 km. Peak winds near 40 m/s.
42	LRFE	2/11/2015	1832	Sky cover N/A. WNW flow below 10 km. WSW flow above 10 km. Peak winds near 40 m/s.
43	LRFE	2/11/2015	2002	Sky cover N/A. WNW flow below 9 km. WSW flow above 9 km. Peak winds near 40 m/s.
44	LRFE	2/11/2015	2117	Sky cover N/A. WNW flow below 8 km. WSW flow above 8 km. Peak winds near 40 m/s.
45	LRFE	2/12/2015	1114	Partly cloudy. Dynamic wind regime. SW flow with peak winds near 40 m/s.
46	LRFE	2/13/2015	1114	Partly cloudy. Dynamic wind regime. SW flow with peak winds near 50 m/s. Enhanced SW flow near 14 km.
47	LRFE	2/16/2015	1114	Mostly cloudy. W flow with peak winds near 60 m/s. Enhanced NW flow near 16 km and SW flow near 17 km.
48	LRFE	2/17/2015	1114	Mostly cloudy. W flow with peak winds near 60 m/s. Enhanced SW flow near 13 km.
49	LRFE	2/19/2015	1114	Clear. Dynamic wind regime. W flow with peak winds near 70 m/s.

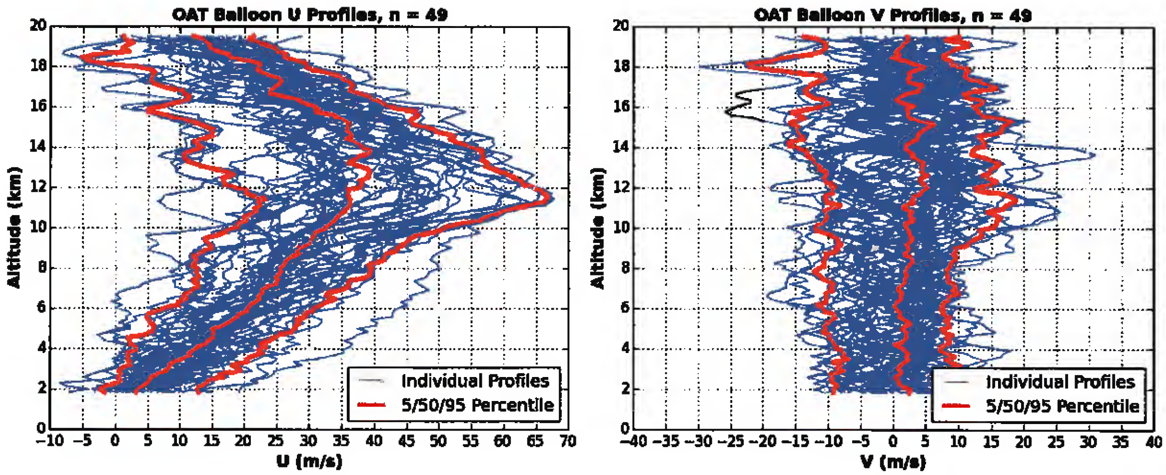

Figure 4: Balloon U-component (left) and V-component (right) profiles used for the OAT. Each plot also contains the median wind and 90% envelope wind at each altitude.

After data QC, statistical analysis was performed on the differences between concurrent DRWP and balloon wind components at the same altitude. Using all reports, the mean U and V differences (DRWP-balloon) were -0.03 m/s and -0.14 m/s, respectively. RMS U and V differences were 2.02 m/s and 2.14 m/s, respectively. These RMS differences exceeded the 1.5 m/s criterion in Table 2, which promoted further investigation of the comparison.

The first of two sensitivity studies of the DRWP / balloon comparison addressed the characteristics of each system. Recall, other than a shear and convection check, the analysis did not implement any QC procedures on DRWP data. In addition, no effort was made to address system noise. The comparison computed the same mean and RMS statistics after adjusting the input data in three additional ways.

(1) Implement a low-pass, six-pole, Butterworth filter on the LRFE profile to remove any artifacts from the LRFE system that would not exist in the 50-MHz DRWP output.
(2) Item (1) and remove DRWP data where any beam's FGP exceeded 4 as the DRWP processing algorithm starts interpolating radial velocity output for FGP exceeding this value.
(3) Item (1), item (2), and remove DRWP data if the DRWP QC flag in the MIDDS output exceeded 3 but was not exactly 64. This operation retained DRWP data only if no QC criteria (shear, FGP, bad data) were flagged, but ignored the QC mode (automatic or manual) and whether or not communication was established from the DRWP site to the operator at the CCWS.

Table 5 shows the sample size; as well as wind component RMS and bias after each adjustment compared to the initial analysis. Neither the bias nor RMS quantity changed by more than 0.03 m/s, which is two orders of magnitude less than the quantity being evaluated and the accepted error of the previous DRWP. In addition, implementing QC item (3) actually increased the negative bias in V. These two characteristics indicated that scrutinizing the quality of the output data from each system provided a negligible effect on the comparison of wind component differences.

Table 5: OAT DRWP / balloon comparison results after implementing a low-pass filter on the LRFE and additional QC checks on DRWP profiles. All bias and RMS results are in m/s.

	Initial Analysis	LRFE Filter	LRFE Filter + FGP QC	LRFE Filter + FGP QC + DRWP QC Flag
N	5426	5426	5345	4989
RMS dU	2.02	2.01	2.01	1.99
RMS dV	2.14	2.14	2.14	2.13
Bias dU	-0.03	-0.03	-0.04	-0.03
Bias dV	-0.14	-0.14	-0.15	-0.16

The second sensitivity study of the DRWP / balloon comparison examined the effect of balloon drift. Figure 5 shows an example of a balloon's zonal and meridional displacement relative to the DRWP's vertical axis throughout the balloon's ascent. Positive zonal (meridional) values indicate balloon position east (north) of the DRWP. The balloons were released at the CCWS, which is located roughly 21 km south-southeast of the DRWP, and followed the wind during ascent. In Figure 5, the balloon drifted to near 105 km east of the DRWP and to about 1 km south of the DRWP by the time the balloon reached 19 km in altitude. The sensitivity study computed the RMS wind component difference for all the reports given that the balloon's total displacement (the root-sum-square of the zonal and meridional displacements) did not exceed a specified threshold. Figure 6 shows the RMS and number of wind component differences as a function of the balloon's displacement from the DRWP. At displacements greater than 30 km, nearly all RMS wind component differences increased monotonically, with minimum RMS wind component differences of around 1.55 m/s. Sample size could attribute to the higher RMS wind component differences at displacements less than 30 km as the dataset of concurrent profiles contained less than 1,000 differences that meet this displacement criterion. These results show that significant balloon drift negatively impacted the DRWP / balloon comparison.

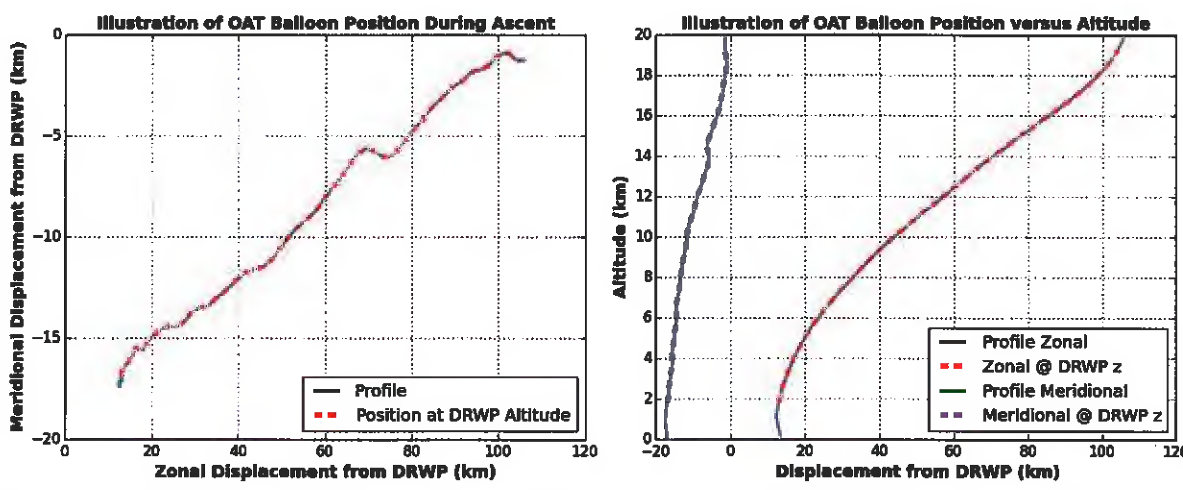

Figure 5: Example of the balloon's zonal and meridional distance from the DRWP on an x-y plane (left) and versus altitude (right).

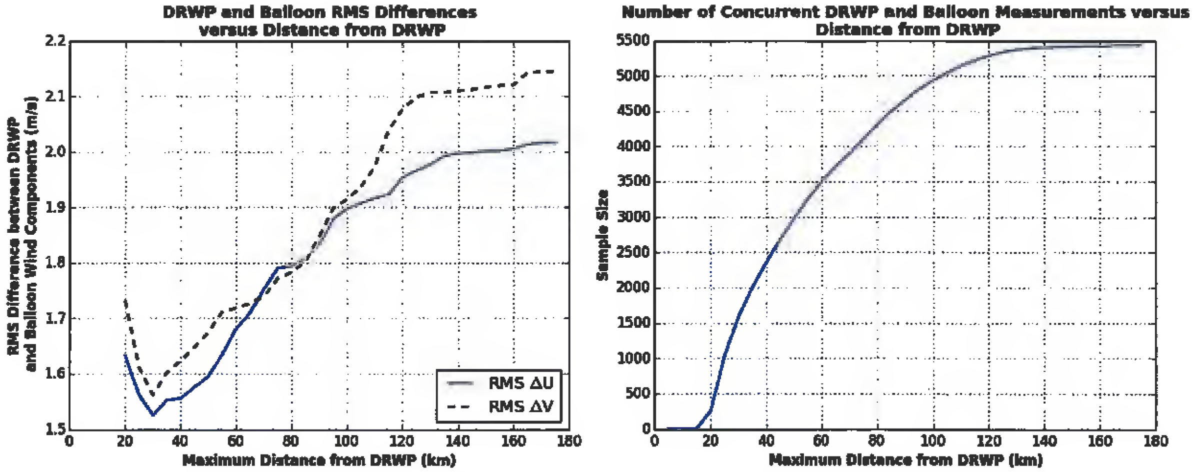

Figure 6: RMS (left) and sample size (right) of wind component differences that are limited by a specified distance from the DRWP.

In conclusion, this analysis showed that the DRWP's wind component "accuracy" was largely affected by balloon drift. The analysis addressed the OAT's intent of determining that the updated DRWP is as good as the previous DRWP, once the balloon's drift characteristics were removed. The RMS difference between DRWP and balloon wind components was 2.02 m/s for U and 2.14 m/s for V. Sensitivity studies revealed that filtering the LRFE to the DRWP Nyquist wavelength and implementing common QC procedures to DRWP data have little effect on the RMS results. However, the balloon's downrange drift did significantly influence this comparison. RMS wind component differences approached the 1.5 m/s criterion in Table 2 in situations where the balloon did not drift far downrange and a large enough sample existed to compute a reliable RMS statistic. These results are consistent with [4], which showed that the RMS wind component differences was near 1.55 m/s when examining winds that did not exist within a significant horizontal wind gradient.

b. DRWP Effective Vertical Resolution Assessment

The EVR analysis utilized all available DRWP data during the OAT collection period, and followed the methodology of an analysis of the previous DRWP's EVR [5] and Jimsphere balloons [10]. For an individual day, the analysis first removed profiles during convective periods (Table 3) and extracted five-minute wind component pairs. Next, the analysis computed the Fast Fourier Transform (FFT) as a function of wavelength on each individual wind component profile on all 119 range gates assuming a 150 m sampling interval. Implementing these inputs results in output at wavelengths ranging from 300-17,850 m. Before computing the FFT, the algorithm removed the mean and linear trend of each profile and used a Parzen window with zero overlap to align with [5] and [10]. From the FFTs, the analysis computed each profile's power spectral density (PSD) and each pair's cross-spectral density (CSD). These quantities were then used to compute the magnitude squared coherence, or "coherence" as this report denotes. Coherence describes the relationship between two signals at each wavelength, where incoherent noise dominates this relationship at values below 0.25 as this value corresponds to a signal-to-noise ratio (SNR) of unity. The coherence was computed as

$$Coh^2 = \frac{|\langle CSD \rangle|^2}{\langle PSD_1 \rangle \langle PSD_2 \rangle}, \tag{1}$$

where brackets denote averages over the entire day at each wavelength, which must be performed in order to avoid the coherence resulting in unity.

The analysis computed the coherence for each day with at least 100 pairs and stores each day's sample size (i.e., number of 5-minute pairs). The composite coherence was then generated by computing a sample-size-weighted coherence at each wavelength. Figure 7 presents this result, which represents the composite wind component coherence for the entire OAT DRWP sample. The composite dataset's coherence remained above 0.25 for all wavelengths above 300 m, which is the DRWP's Nyquist limit, for both U and V. Thus, the DRWP's EVR is limited by the system's sampling interval. Communication with the authors of [5] and [10] during this report revealed that the 500 m EVR quoted in [5] resulted from its author mistakenly using 0.5 as the SNR cutoff instead of 0.25. Despite this artifact, the computations and characteristics of daily coherence in [5] remained accurate, and this analysis derived similar results. First, the composite coherence remained above 0.25 for all wavelengths greater than 300 m in [5], which implied that the previous DRWP's EVR was also Nyquist-limited. Thus, the new DRWP's EVR was found to be just as good as the previous DRWP's EVR. Second, this analysis was subject to anisotropic cases where different characteristics of U and V coherence existed as in [5]. As a result, the analysis found some cases where the boundary wavelengths, or the wavelengths at which the coherence is 0.25, exceeded 300 m from daily-averaged U and V coherence. The boundary wavelength from daily-averaged U and V coherence ranged from 300-358 m and 300-486 m, respectively. A sensitivity study using Hanning and Hamming windows produced a composite EVR of 300 m for both wind components with very similar maximum boundary wavelengths from daily-averaged U and V coherence.

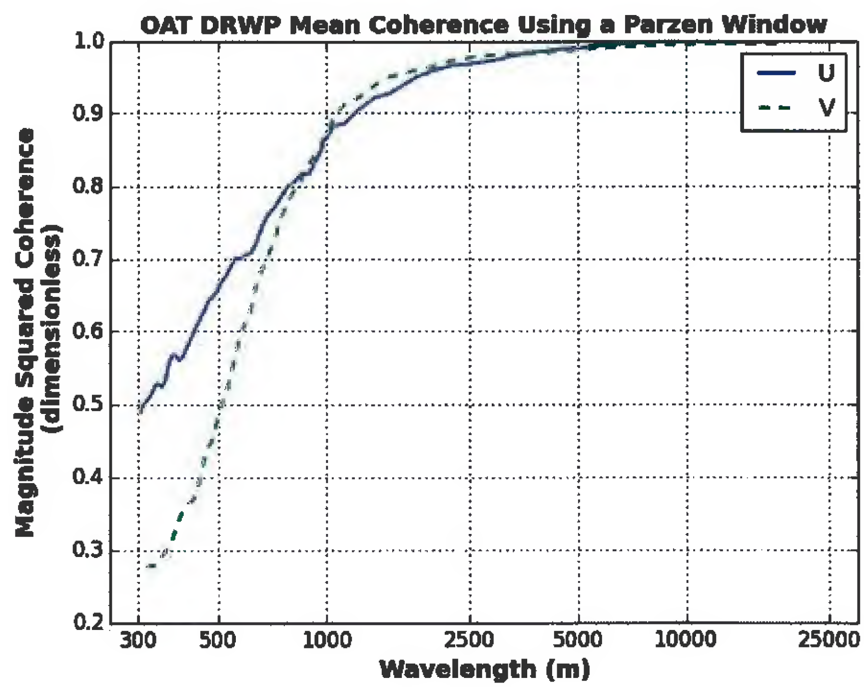

Figure 7: DRWP composite coherence for U (solid blue line) and V (dashed green line) as a function of wavelength using a Parzen window.

In conclusion, the OAT EVR analysis showed that the new DRWP's EVR is as good as the previous DRWP, which addressed the OAT's intent. The boundary wavelength of the composite U and V coherence over the OAT's period was 300 m, which is the Nyquist limit of the DRWP system. The previous DRWP had the

same characteristic. It should be noted that, to characterize the EVR in more detail, anisotropic events should be isolated. However, such an analysis was not performed for the OAT because the criterion that Table 2 defines represents a composite of all days addressed in [5].

c. Vertical Data Coverage Analysis

The vertical data coverage analysis addressed the DRWP's altitude extent of data that contains a signal strong enough so as not to introduce any errors from previously recorded winds. The DRWP's unique MFFG processing algorithm, which was developed for the previous DRWP [12] and implemented on the new DRWP, enables the DRWP to generate a wind record at every altitude using a first-guess velocity. This attribute meets the altitude and vertical interval specifications in Table 2. However, like all profilers, certain atmospheric conditions and / or instrument settings can limit the DRWP's signal return at higher altitudes. The MFFG algorithm uses the previous first-guess velocity in situations when the updated DRWP's SNR falls below -30 dB (compared to -15 dB with the previous system). This process of first guess "propagating" essentially uses a wind that is an additional five minutes old as input to the current radial velocity computation. Thus, adding an FGP could introduce errors in the radial velocity estimate, especially in dynamic wind environments and / or if a non-atmospheric signal exists near the signal associated with the real wind [12]. In addition, these errors could compound over time and the algorithm smoothes the radial velocity estimate if greater than four FGPs exist. Both of these characteristics provide evidence for addressing the DRWP output associated with a large number of FGPs for situational awareness (and possibly removal) of possibly erroneous data, and thus warrant an assessment of how often specified FGP thresholds were exceeded.

This analysis computed the percentage of data records at each altitude that did not exceed a given FGP threshold using all 9,300 profiles from the available DRWP data during the OAT collection period. No QC procedures were implemented in order to characterize the amount of data availability and to avoid removing output associated with an incremented FGP. Applying the latter of would contaminate analysis results. The analysis selected FGP thresholds corresponding to 30-minute increments over which the first-guess velocity would be propagated. The percentage of reports containing an FGP from all beams that did not exceed thresholds of 0-24 FGPs at 6-FGP intervals are computed and plotted at each altitude. The result thus represents the percentage of the data from which the MFFG algorithm used first-guess velocities, which were generated from winds that occur 0-120 minutes, at 30-minute intervals, before the time of interest. Figure 8 shows that the FGP check primarily affects data above 7 km, where weak signal return dominates. Below 7 km, isolated instances of other events that propagate the first guess velocity (e.g., excessive radial shear) likely caused FGP increases. If one does not tolerate incrementing the FGP, then the amount of available data at a given altitude decreases from near 100% at roughly 7 km to about 58% at the DRWP's maximum altitude, with a general (but not monotonic) decrease in the amount of available data as altitude increases above 7 km. Increasing the FGP threshold to 6 and 12 produces data availability of at least 90% and at least 95%, respectively. A sensitivity study examining data availability for all FGPs found that implementing an FGP threshold of at least 44 retained all data at all altitudes.

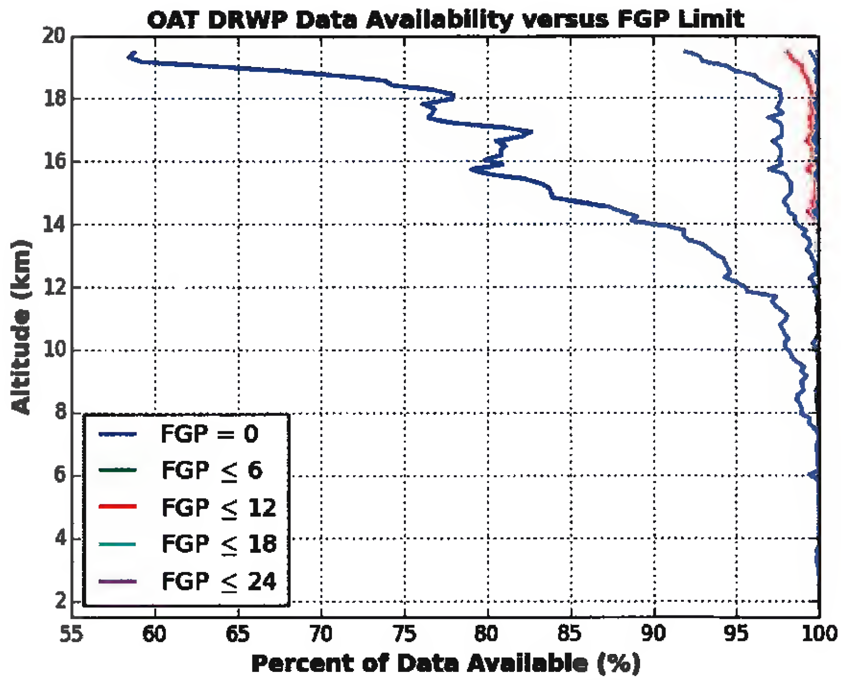

Figure 8: Percent of DRWP data available at each altitude after implementing different FGP thresholds.

In summary, the vertical data coverage assessment verified that each DRWP profile contains a wind record at every altitude from 1798-19645 m, which addressed the OAT's intent. Additionally, the analysis presented sensitivities to incrementing the first-guess velocity to provide situational awareness of the DRWP's signal acquisition capability. DRWP users have the responsibility to determine the applicability of implementing FGP criteria. Examples could consist of determining the measurement errors associated with incrementing each beam's first-guess velocity [8] for this system, rejecting a first-guess velocity generated from a wind before a pre-determined time before assessment [6, 11], or comparing suspect DRWP output to output from other sources.

5. Conclusion

This report provides evidence to accept the new DRWP by showing that the new DRWP meets the criteria specified in [2] and performs as well as the previous DRWP. Complete profiles exist every five minutes from 1798-19645 m every 150 m, which address the "time interval", "vertical data interval", and "altitude" specifications in Table 2. Analysis of "wind accuracy" found RMS differences between concurrent DRWP and AMPS balloon wind components of near 2.0 m/s. These RMS differences decreased to around 1.5 m/s if the balloon measurement existed within 30 km of the DRWP. Analysis of the DRWP's EVR showed that the DRWP can resolve atmospheric features above approximately 300 m for U and V using all available data. A final analysis determined the sensitivity of the DRWP's vertical data coverage to signal return for situational awareness.

In conclusion, the report recommends accepting the DRWP for situational awareness during mission operations at the ER.

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